U.S. Department
of Transportation

Federal Aviation
Administration

Advisory Circular

subject: AIRCRAFT WAKE TURBULENCE

Date: 10/1/91
Initiated by: AFS-430

AC No: 90-23E
Change:

1. PURPOSE. This advisory circular (AC) is intended to alert pilots to the hazards of aircraft wake turbulence and recommends related operational procedures.

2. CANCELLATION. AC 90-23D, Aircraft Wake Turbulence, dated 12/15/72.

3. INTRODUCTION. Every aircraft in flight generates a wake. Historically, when pilots encountered this wake the disturbance was attributed to "prop wash." It is known, however, that this disturbance is caused by a pair of counterrotating vortices trailing from the wing tips. The vortices from large aircraft pose problems to encountering aircraft. For instance, the wake of these aircraft can impose rolling moments exceeding the control authority of the encountering aircraft. Further, turbulence generated within the vortices, if encountered at close range, can damage aircraft components and equipment and cause personal injuries. The pilot must learn to envision the location of the vortex wake generated by larger (transport category) aircraft and adjust his/her flight path accordingly.

4. VORTEX GENERATION. Lift is generated by the creation of a pressure differential over the wing surfaces. The lowest pressure occurs over the upper wing surface and the highest pressure under the wing. This pressure differential triggers the rollup of the airflow aft of the wing resulting in swirling air masses trailing downstream of the wingtips. After the rollup is completed, the wake consists of two counterrotating cylindrical vortices (see figure 1). Most of the energy is within a few feet of the center of each vortex, but pilots should avoid a region within about 100 feet of the vortex core.

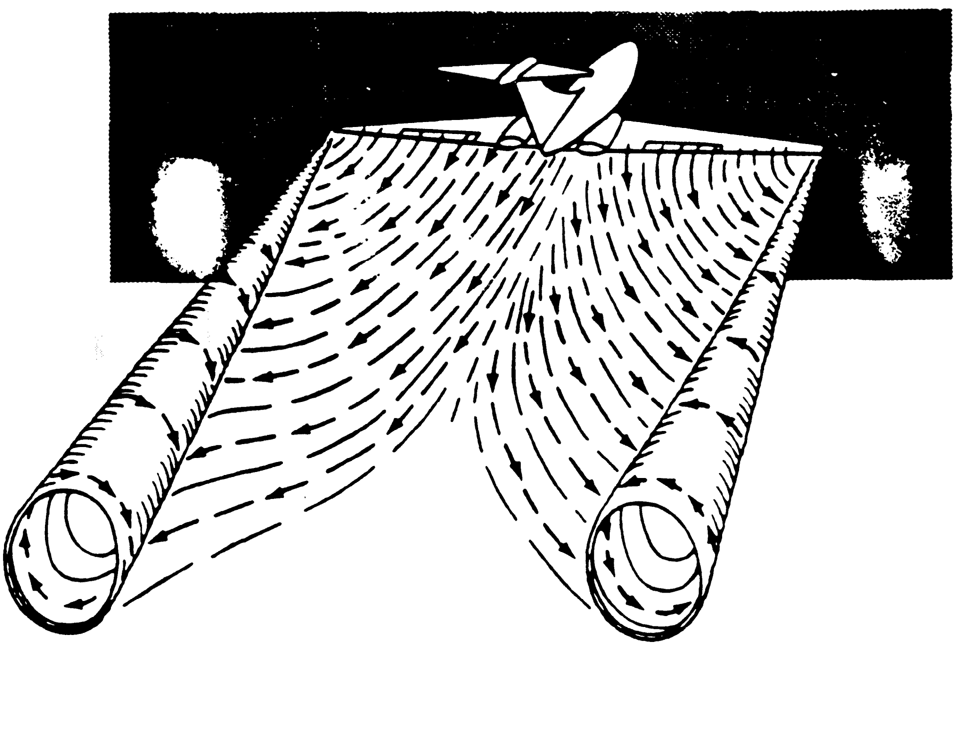


FIGURE 1. The rolling up process

5. __VORTEX STRENGTH.__ The strength of the vortex is governed by the weight, speed. and shape of the wing of the generating aircraft. The vortex characteristics of any given aircraft can also be changed by extension of flaps or other wing configuring devices. However, as the basic factor is weight, the vortex strength increases proportionately with increase in aircraft operating weight. Peak vortex tangential speeds up to almost 300 feet per second have been recorded. The greatest vortex strength occurs when the generating aircraft is __heavy-clean-slow__. Figure 2 shows smoke visualization of a vortex photographed during early smoke tower fly-by tests.

FIGURE 2. Typical vortex flow field outlined by smoke

6. __INDUCED ROLL.__

a. In rare instances, a wake encounter could cause in-flight structural damage of catastrophic proportions. However, the usual hazard is associated with induced rolling moments which can exceed the roll control capability of the encountering aircraft. In flight experiments, aircraft have been intentionally flown directly up trailing vortex cores of larger aircraft. It was shown that the capability of an aircraft to counteract the roll imposed by the wake vortex primarily depends on the wing span and counter-control responsiveness of the encountering aircraft.

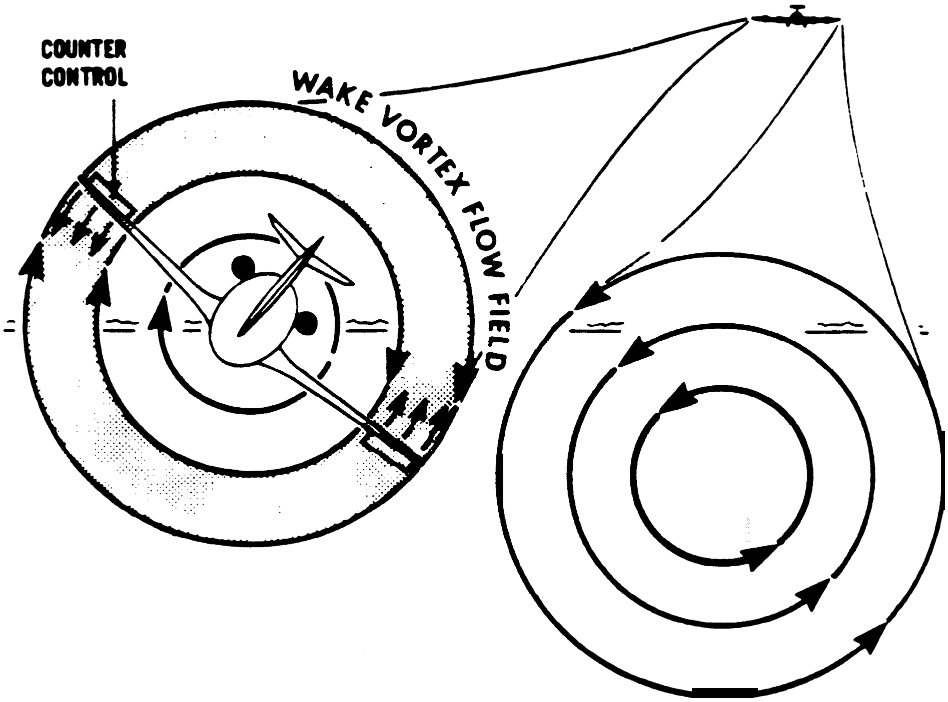


FIGURE 3. Induced Roll

b. Counter-control is usually effective and induced roll minimal in cases where the wing span and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. It is more difficult for aircraft with short wing span (relative to the vortex generating aircraft) to counter the imposed roll induced by vortex flow. Pilots of short-span aircraft, even of the high performance type, must be especially alert to vortex encounters. The wake of large aircraft requires the respect of all pilots. (See figures 3 and 4.)

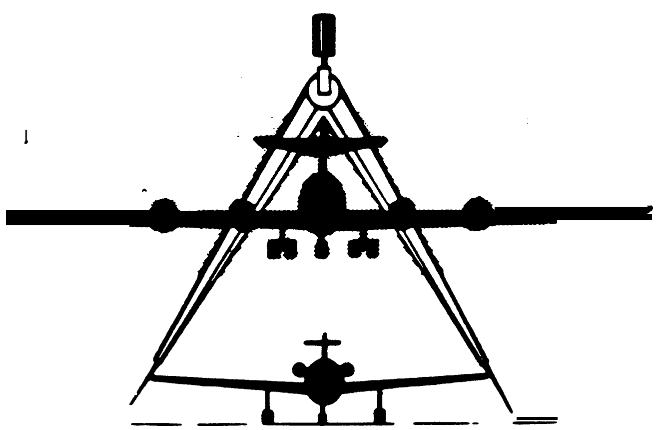


FIGURE 4. Relative Span

7. VORTEX BEHAVIOR. Trailing vortices have certain behavioral characteristics which can help pilot visualize the wake location and thereby take avoidance precautions.

a. Vortices are generated from the moment aircraft leave the ground, since trailing vortices are a by-product of wing lift. Prior to takeoff or landing, pilots should note the rotation or touchdown point of the preceding aircraft. (See figure 5.)

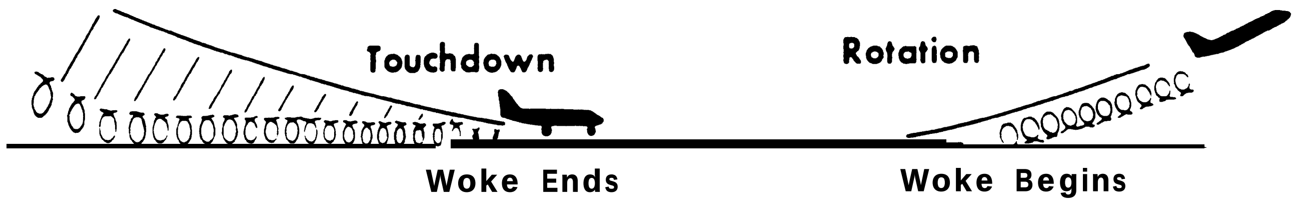


FIGURE 5.

b. The vortex circulation is outward, upward, and around the wing tips when viewed from either ahead or behind the aircraft. Tests with large aircraft have shown that the vortices remain spaced a bit less than a wing span apart drifting with the wind, at altitudes greater than a wing span from the ground. In view of this, if persistent vortex turbulence is encountered. a slight change of altitude and lateral position (preferably upwind) will provide a flightpath clear of the turbulence.

c. Flight tests have shown that the vortices from larger (transport category) aircraft sink at a rate of several hundred feet per minute, slowing their descent and diminishing in strength with time and distance behind the generating aircraft. Atmospheric turbulence hastens breakup. Pilots should fly at or above the preceding aircraft's flightpath, altering course as necessary to avoid the area behind and below the generating aircraft. However, vertical separation of 1,000 feet may be considered safe. (See figure 6.)

d. When the vortices of larger aircraft sink close to the ground (within 100 to 200 feet), they tend to move laterally over the ground at a speed of 2 or 3 knots. (Figure 7.)

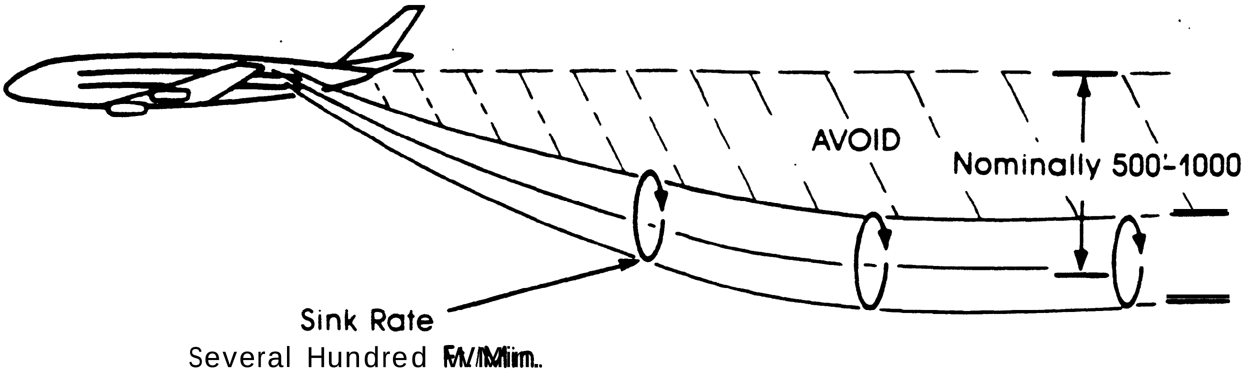


FIGURE 6

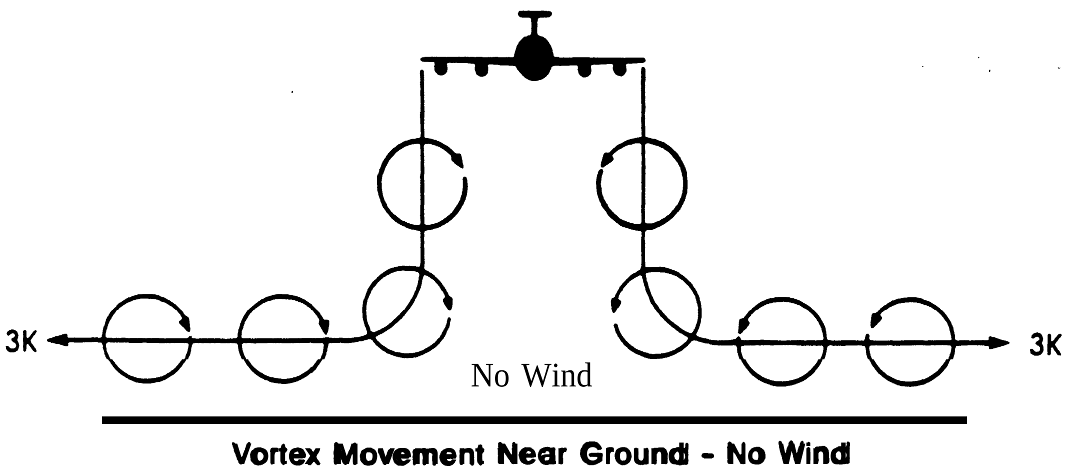
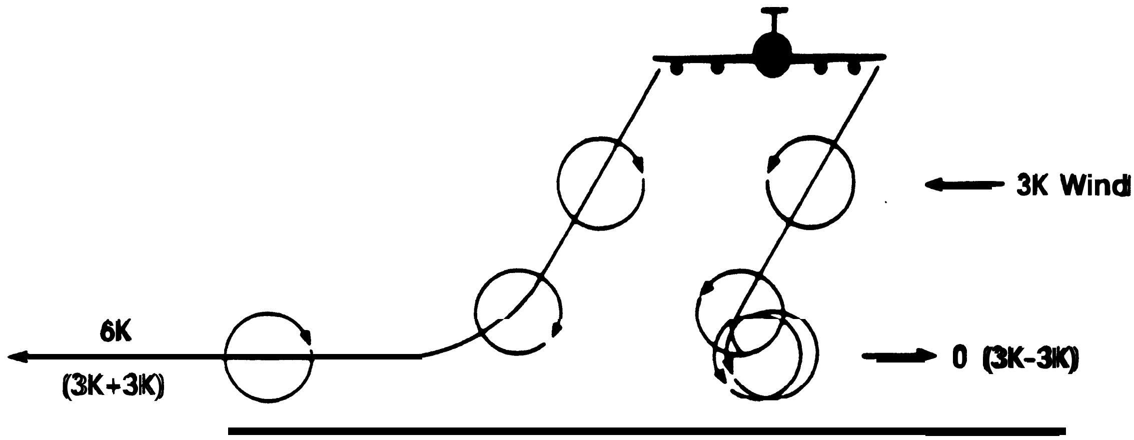


FIGURE 7

e. A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex (figure 8). Thus, a light wind with a cross-runway component of 1 to 5 knots (depending on conditions) could result in the upwind vortex remaining in the touchdown zone for a period of time (figure 9) and hasten the drift of the downwind vortex toward another runway. Similarly, a tailwind condition can move the vortices of the preceding aircraft forward into the touchdown zone. The light quartering tailwind requires maximum caution. Pilots should be alert to larger aircraft upwind from their approach and takeoff flightpaths.



Vortex Movement Near Ground - with Cross Wind

FIGURE 8

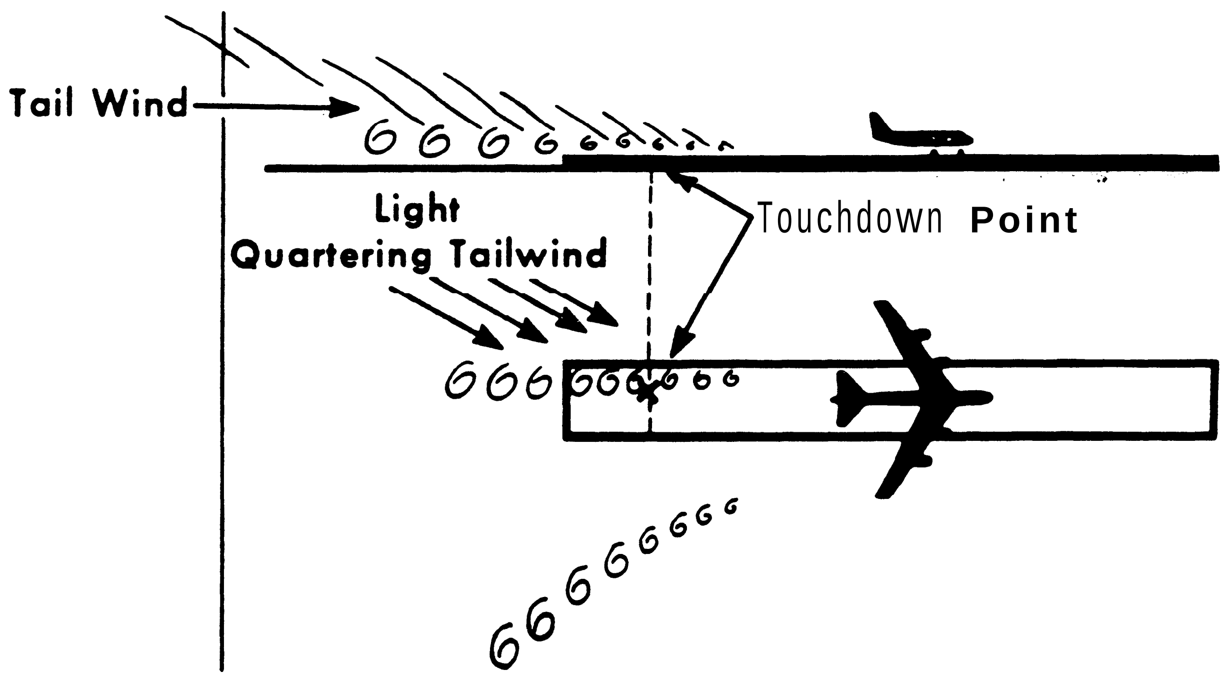


FIGURE 9

8. <u>OPERATIONAL PROBLEM</u> AREAS. A wake encounter is not necessarily hazardous. It can be one or more jolts with varying severity depending upon the direction of the encounter, weight of the generating aircraft, size of the encountering aircraft, distance from the generating aircraft, and point of vortex encounter. The probability of induced roll increases when the encountering aircraft's heading is generally aligned or parallel with the flightpath of the generating aircraft. <u>Avoid the area below and behind the generating</u>

aircraft, especially at low altitude where even a momentary wake encounter could be hazardous. Pilots should be particularly alert in calm wind conditions and maneuvering situations in the vicinity of the airport where the vortices could:

a. Remain in the touchdown area.

b. Drift from aircraft operating on a nearby runway.

c. Sink into takeoff or landing path from crossing runway.

d. Sink into the traffic patterns from other airport operations.

e. Sink into the flight path of aircraft operating under Visual Flight Rules and at hemispheric altitudes 500 feet below.

f. Pilots of all aircraft should visualize the location of the vortex trail behind larger aircraft and use proper vortex avoidance procedures to achieve safe operation. It is equally important that pilots of larger aircraft plan or adjust their flightpaths, whenever possible, to minimize vortex exposure to other aircraft.

9. VORTEX AVOIDANCE PROCEDURES. Under certain conditions, airport traffic controllers apply procedures for separating aircraft operating under Instrument Flight Rules. The controllers will also provide to VFR aircraft, with whom they are in communication and which in the tower's opinion may be adversely affected by wake turbulence from a larger aircraft, the position, altitude and direction of flight of larger aircraft followed by the phrase "caution - wake turbulence." Whether or not a warning has been given, however, the pilot is expected to adjust his/her operations and flightpath as necessary to preclude serious wake encounters. The following vortex avoidance procedures are recommended for the situation shown:

a. When landing behind a larger aircraft - same runway (figure 10), stay at or above the larger aircraft's final approach flightpath--note touchdown point--land beyond it.

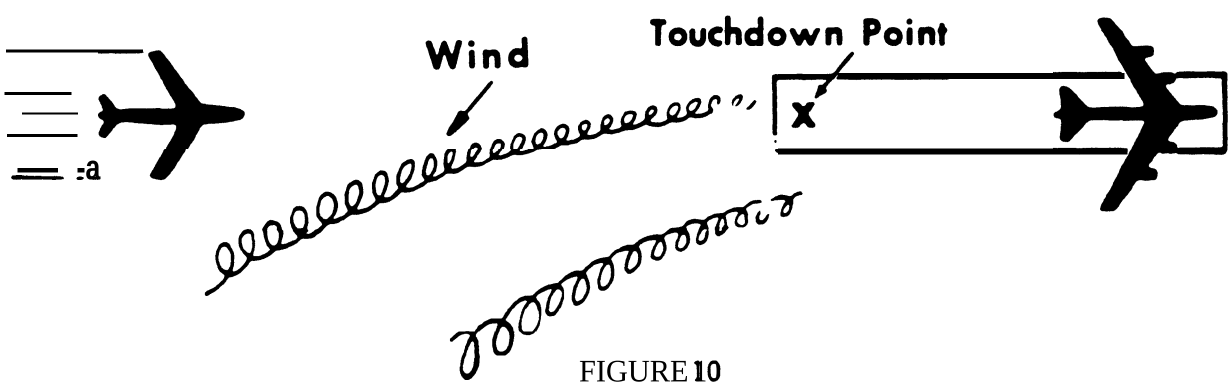


FIGURE 10

b. When landing behind a larger aircraft - when parallel runway is closer than 2,500 feet (figure 11), consider possible vortex drift onto your runway. If you have visual contact with the larger aircraft landing on the parallel runway, whenever possible, stay at or above the larger aircraft's final approach flightpath -- note its touchdown point.

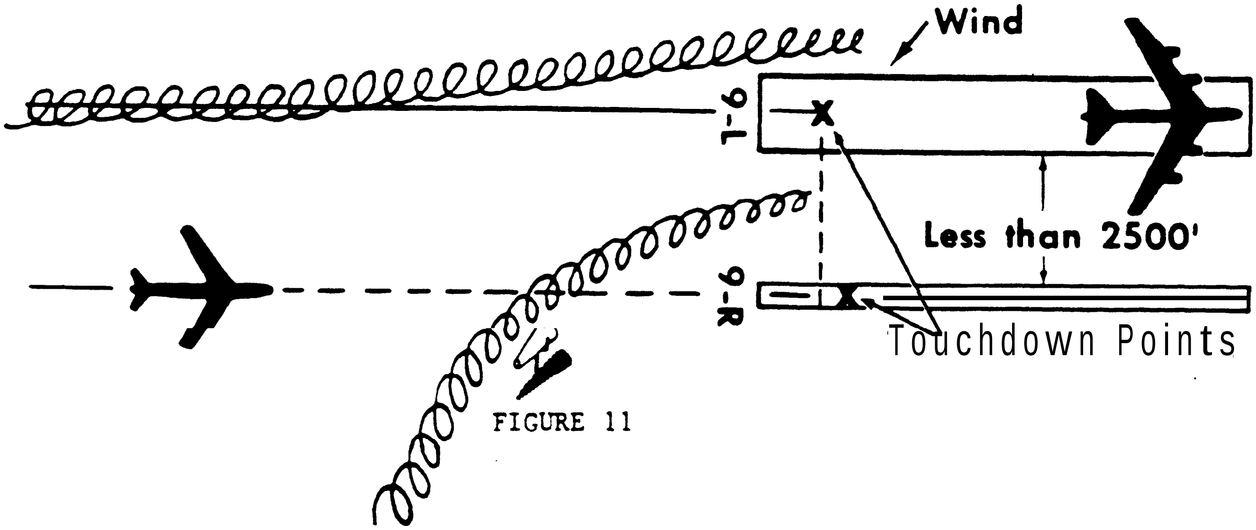


FIGURE 11

c. When landing behind a larger aircraft - crossing runway (figure 12), cross above the larger aircraft's flightpath.

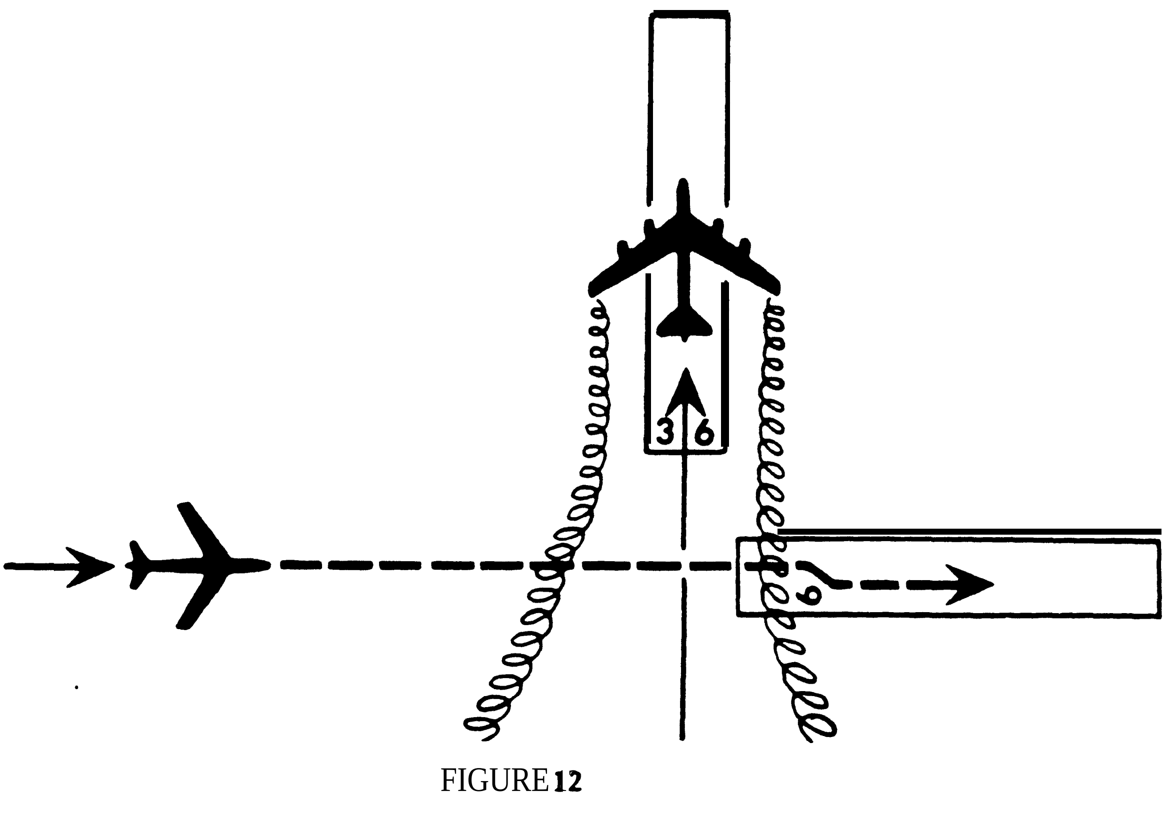


FIGURE 12

d. **When landing** behind a departing **larger aircraft** - same runway (**figure 13**), note larger aircraft's rotation point--land well **prior** to rotation point.

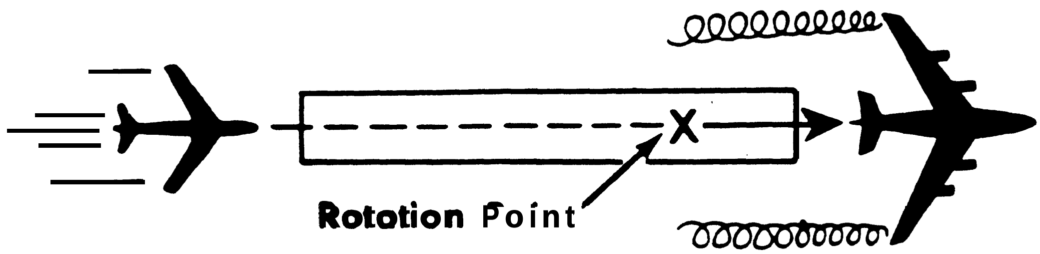


FIGURE 13

e. When landing behind a departing larger **aircraft** - crossing runway, note larger aircraft's rotation point--if past the intersection--continue the approach--land prior to the intersection (figure **14**). If larger **aircraft** rotates prior to the intersection, avoid **flight** below the larger aircraft's flightpath. Abandon the approach unless a landing is ensured well before reaching the intersection (figure **15**).

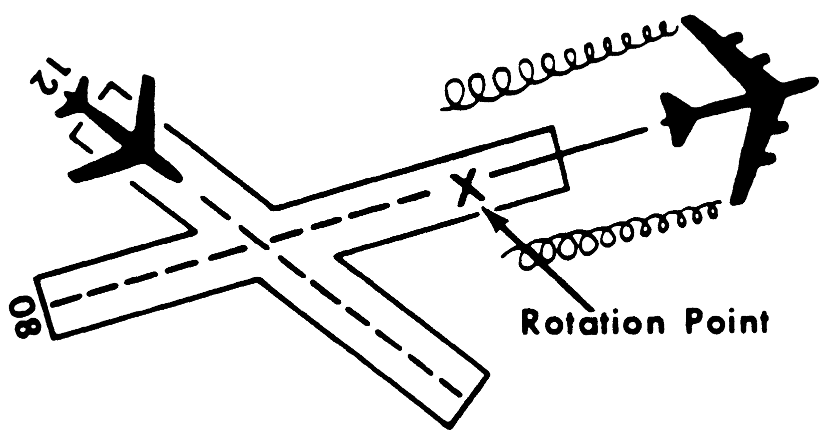


FIGURE 14

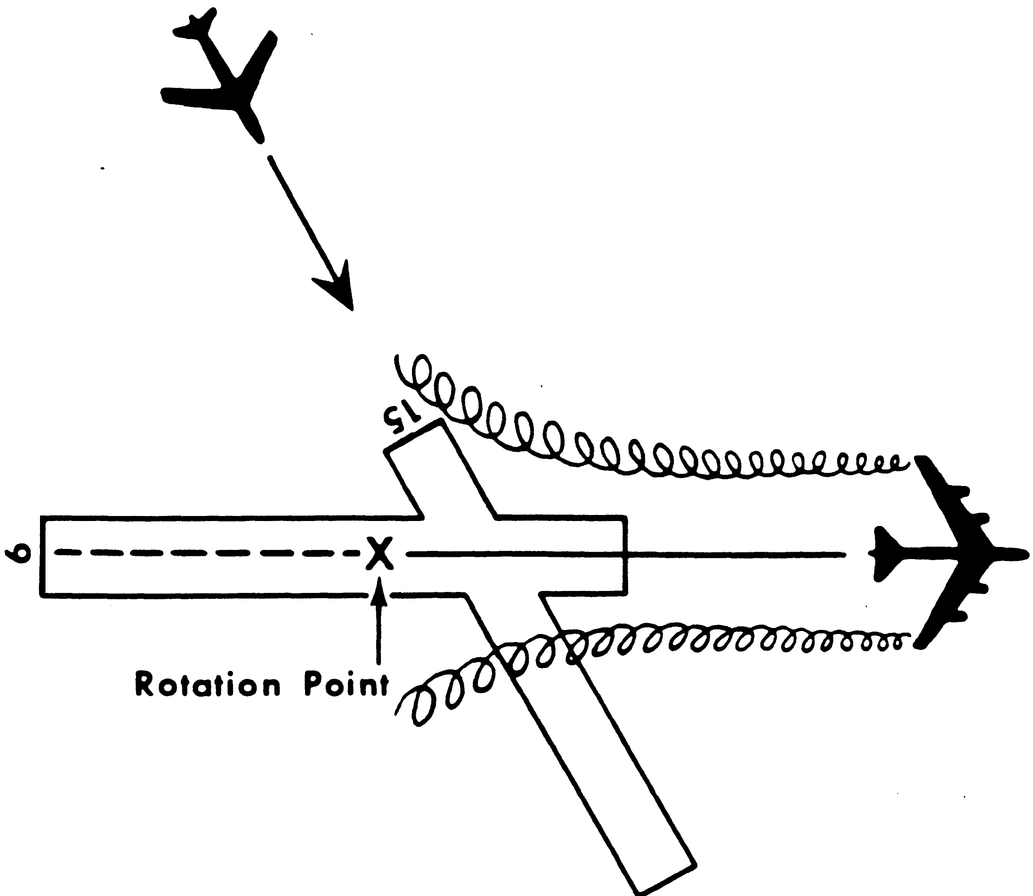


FIGURE 15

f. When departing behind a larger aircraft: Note larger aircraft's rotation point--rotate prior to larger aircraft's rotation point-continue climb above the larger aircraft's climb path until turning clear of this wake (figure 16). Avoid subsequent headings which will cross below and behind aircraft (figure 17). Be alert for any critical takeoff situation which could lead to a vortex encounter.

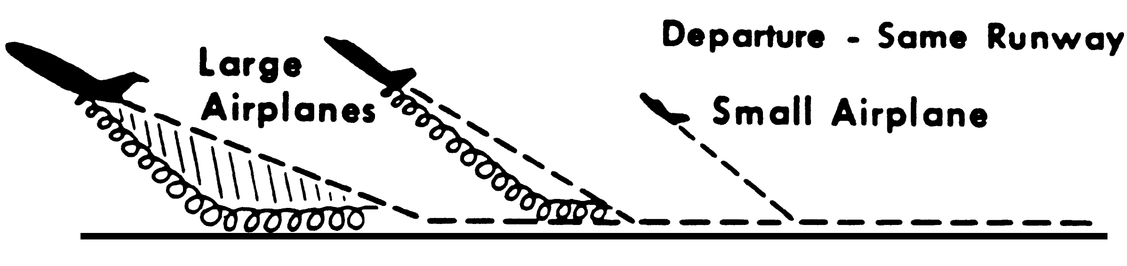


FIGURE 16

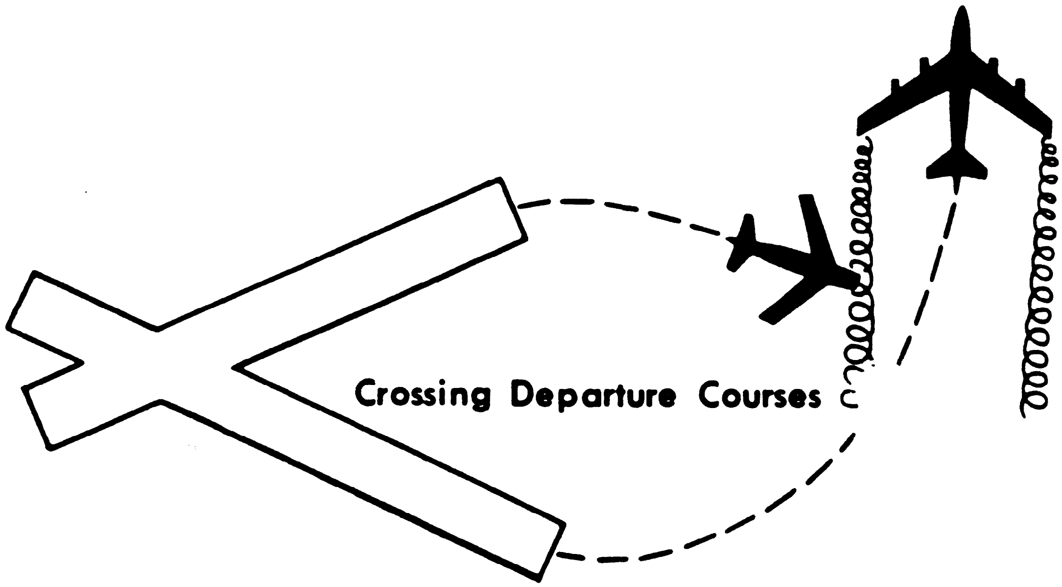


FIGURE 17

g. **Intersection takeoffs - same runway**, be alert to adjacent large aircraft operations particularly upwind of your runway. If intersection takeoff clearance is received, avoid subsequent heading which will cross below a larger aircraft's path.

h. Departing or landing after a larger aircraft executing a low missed approach or touch-and-go landing. Because vortices settle and move laterally near the ground, the vortex hazard may exist along the runway and in your flightpath after a larger aircraft has executed a low missed approach or a touch-and-go landing, particularly in light quartering wind conditions. You should ensure that an interval of at least 2 minutes has elapsed before your takeoff or landing.

i. En route VFR - (thousand-foot altitude plus 500 feet). Avoid flight below and behind a larger aircraft's path. If a larger aircraft is observed above on the same track (meeting or overtaking), adjust your position laterally, preferably upwind.

10. <u>HELICOPTERS.</u> A hovering helicopter generates a downwash from Its main rotor(s) similar to the "prop wash" of a conventional aircraft. However, in forward flight, this energy is transformed into a pair of strong, high-speed trailing vortices similar to wing-tip vortices of larger fixed-wing aircraft. Pilots should avoid helicopter vortices since helicopter forward flight airspeeds ate often very low which generate exceptionally strong vortices (figure 18).

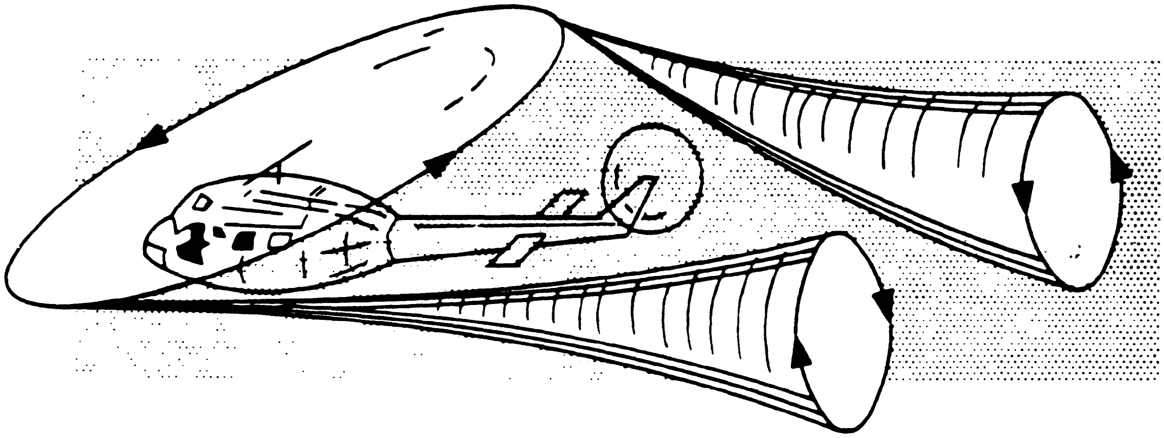
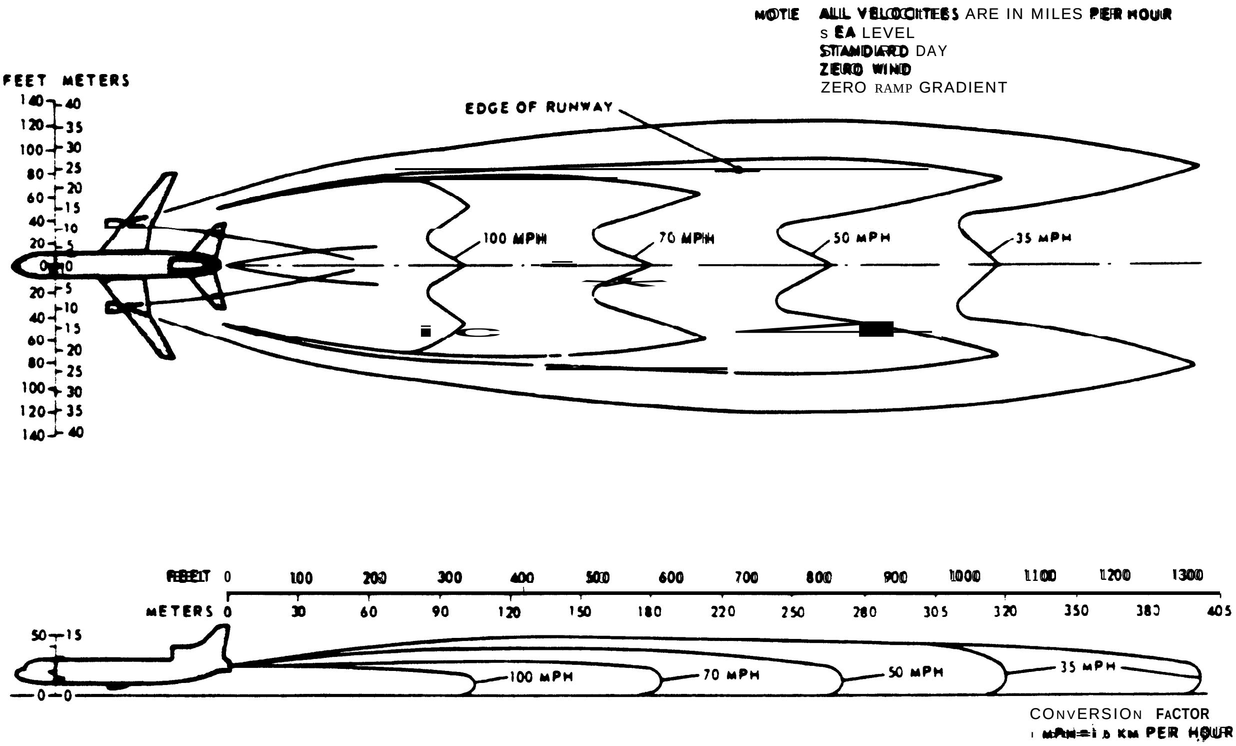


FIGURE 18. Helicopter Vortices.

11. <u>JET ENGINE EXHAUST.</u> During ground operations, jet engine blast (thrust stream turbulence) can cause damage and upsets if encountered at close range. Exhaust velocity versus distance studies at various thrust levels have shown a need for light aircraft to maintain an adequate separation during ground operations (figure 19).

a. Engine exhaust velocities, generated by larger jet aircraft during ground operations and initial takeoff roll, dictate the desirability of lighter aircraft awaiting takeoff to hold well back of the runway edge at the taxiway hold line. Also, it is desirable to align the aircraft to face any possible jet engine blast effects. Additionally, in the course of running up engines and taxiing on the ground, pilots of larger aircraft should consider the effects of their jet blasts on other aircraft, vehicles, and maintenance and servicing equipment. An illustration of exhaust velocities behind a typical *"wide-body"* or jumbo jet is shown in figure 19.



JET ENGINE EXHAUST VELOCITY CONTOURS, TAKEOFF POWER

FIGURE 19

b. The Federal Aviation Administration has established standards for the location of runway hold lines. For example, runway intersection hold short lines are established 250 feet from the runway centerline for precision approach runways served by approach category C and D aircraft. For runways served by aircraft with wingspans over 171 feet, such as the B-747, taxiway hold lines are 280 feet from the centerline of precision approach runways. These hold line distances increase slightly with an increase in field elevation.

12. PILOT RESPONSIBILITY. Government and industry groups are making concerted efforts to minimize or eliminate the hazards of trailing vortices. However, the flight disciplines necessary to ensure vortex avoidance during visual operations must be exercised by the pilot. Vortex visualization and avoidance procedures should be exercised by the pilot using the same degree of concern as in collision avoidance since vortex encounters frequently can be as dangerous as collisions.

a. **Pilots** are reminded that **in operations** conducted behind all aircraft, acceptance from Air Traffic Control of **traffic information,** instructions to follow an aircraft, or the acceptance of an visual approach clearance, **is** an acknowledgment that the pilot will ensure safe takeoff and **landing** Intervals and accepts the responsibility of providing his/her own wake turbulence **separation.**

b. For **VFR** departures behind heavy aircraft, air traffic controllers are **required** to **use** at least a **2-minute** separation interval unless a pilot has initiated a request to deviate from the **2-minute** interval and has **indicated** acceptance of responsibility for **maneuvering** his/her aircraft so as to avoid the **wake** turbulence hazard.

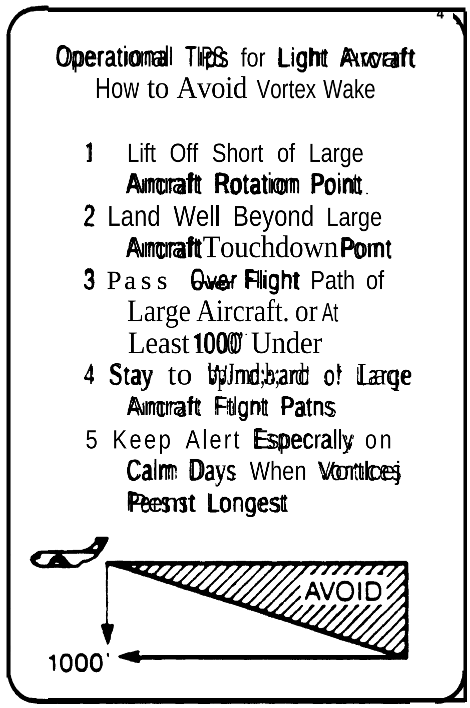


FIGURE 20

David S. Potter
Acting Director, Flight Standards Service

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